

XIII. *On Acquired Radio-Activity.**By* SIR WILLIAM CROOKES, O.M., LL.D., D.Sc., Pres.R.S.

[PLATES 9-10.]

Received October 26, 1914.

Experiments with Cathode Rays.

1. ABOUT forty years ago I sealed in a vacuum tube a yellow diamond cut as a brilliant. This diamond was chosen because it phosphoresced in the dark after exposure to bright sunshine,—it also phosphoresced slightly under the influence of ultra-violet light. In the vacuum tube, as the anti-cathode, it emitted a brilliant yellowish white light giving almost as much light as a candle. It was often exhibited to illustrate the glow of a diamond under the influence of cathode rays *in vacuo*; scarcely a week passed without the vacuum tube containing the diamond being exhibited to friends. It was by far the most attractive tube in my collection. After forty years of hard work the diamond has become much discoloured. It was of interest to see if the repeated bombardment, as the anti-cathode, in the vacuum tube had conferred radio-activity on the diamond. Accordingly I opened the tube, quickly removed the diamond, and in the dark put it on a sensitive film, a thin sheet of black paper intervening. Over the diamond was placed a pad of cotton-wool and a weight, to prevent the stone from shifting its position. After nine days' contact the film was developed. An exceedingly slight action could, with difficulty, be detected, showing that the off and on action for forty years had conferred practically no radio-activity on the diamond.

2. A sensitive electroscope was now made, with sulphur insulation. The fall of the leaf was observed with a small telescope having a photographed scale. The normal fall due to natural leakage was 5° in 165 seconds. A piece of a thoria gas mantle caused a fall of 5° in two seconds, and radio-active diamonds caused a fall in from two or three seconds to a fraction of a second. Tested in this instrument I found this special diamond to be entirely devoid of action.

Action of Cathode Rays on Diamond.

3. On one occasion when M. MOISSAN was in my laboratory I darkened some diamonds by means of cathode rays. One of these he took away, and subsequently reported the result of his experiments to the French Academy.* He heated

* 'Comptes Rendus,' vol. cxxiv., No. 13, p. 653, March, 1897.

the diamond to 60° C. in an oxidising mixture of potassium chlorate and fuming nitric acid, prepared from monohydrated sulphuric acid and potassium chlorate fused and free from moisture (9, 12, 32). The action on the dark layer is very slow, requiring at least eight or ten days for its complete removal. There is at first produced graphitic oxide which at an increased temperature yields pyrographitic acid easily destroyed by nitric acid. Hence the variety of carbon which coated the diamond is graphite. The transformation of diamond into graphite requires the temperature of the electric arc, and the higher the temperature at which it is formed the greater is its resistance to oxidation. M. MOISSAN came to the conclusion that the temperature reached by the surface of the diamond blackened in my radiant matter tube was probably about 3600° C.

4. Six diamonds—having different degrees of phosphorescence under cathode rays—were tested in a Becquerel phosphoroscope to see if the order of intensity of the residual phosphorescence due to illumination with an arc light was the same as the order under cathode rays. All had a slight residual phosphorescence, but the order of intensity differed in the two cases.

Action of Cathode Rays on various Mineral Substances.

5. For many years I have experimented on the changes produced in ordinary and quartz glass and various crystals by exposure to radium emanations and rays.

Considering the identity of the cathode discharge in a high vacuum tube with the β -rays from radium, experiments were started to ascertain if the cathode rays would confer radio-activity in various solid bodies submitted to its influence. A vacuum tube was prepared with a removable window at one end to allow the contents to be exchanged for other bodies. In the tube were placed pieces of uranium glass, a crystal of ruby, a crystal of garnet, a piece of quartz, a plate of platinum and one of gold. The tube was exhausted to a high vacuum just short of the non-conducting point. On excitation the whole tube was filled with the green glow of phosphorescent glass, the ruby and uranium glass became very phosphorescent, the other bodies remained quite dark. After an hour's exposure to the cathode discharge the tube was opened, the objects quickly removed in the dark and placed on a sensitive film; the upper sides that had received most bombardment being placed downwards on the film. They were kept thus for eighteen hours and the film then developed. There was absolutely no impression of any of the bodies on the film. Thus it appears that the cathode stream will not confer radio-activity on the above-named bodies.

Action of Cathode Rays on Phosphorescent Bodies.

6. Experiments were next tried to see if earths and compounds which became strongly phosphorescent under the influence of the cathode discharge would thereby

become radio-active. Some ignited yttrium sulphate, in the condition most sensitive to the cathode rays, and giving under their action a phosphorescent glow with a discontinuous spectrum, was pressed tightly into a shallow aluminium tray and exposed for an hour to the discharge in the vacuum tube. It was then removed and immediately covered with a sensitive film pressed down with a slight weight. After forty-eight hours in total darkness the film was developed. Only a very slight image of the yttria was visible. This result does not prove that the cathode stream had rendered the yttria radio-active, for there is always a residual glow in the yttria in these circumstances; it is not unlikely that the light of this glow, acting for the first hour or so of the forty-eight, might have been strong enough to impress the film (7).

7. Three shallow trays were filled—one with phosphorescent calcium sulphide, another with zinc sulphide, and a third with platinocyanide of barium. After subjecting them to the cathode stream in the above manner, they were removed and covered with a sensitive film, and kept in darkness for twenty-four hours. On development only an impression of the zinc sulphide was seen. As this sulphide also has a certain amount of residual glow after exposure to the cathode rays it is probable that the photographic action is only the result of this glow (6).

Action of Radium on Diamond.

In June, 1904,* I read a paper before the Royal Society on the action of Radium on Diamond.

8. A few years later I repeated the original experiment, exposing two New South Wales diamonds to the action of the radium rays and emanations for a longer period. The diamonds selected were of an identical pale yellow, devoid of radio-activity. A quartz tube, containing 15 mgrms. of pure radium bromide was well exhausted and sealed before the oxy-hydrogen blowpipe. One of the diamonds (fig. 3a) was put close to the tube of radium and kept in its place with a piece of gummed paper. The other diamond (fig. 3b) was put away in a cabinet and kept far from any radium compound. The two diamonds were thus left for a little more than six months. At the end of this time they were examined. No appreciable difference could be detected in the colour of the two diamonds—the one (fig. 3a) that had been close to the tube of radium bromide not being darker than the one (fig. 3b) which had been away from radium the whole time.

Coloration of Diamond by α -Ray.

9. The diamond, 3a, was now enclosed for seventy-eight days in a tube containing radium bromide; at the end of the time it had acquired a bluish green colour. It was

* 'Roy. Soc. Proc.' vol. lxxiv., p. 47.

then heated for ten days in a mixture of fuming nitric acid and potassium chlorate so as to dissolve off any outer skin of graphite which might have contributed to the colour (3, 12, 32). This treatment brightened its appearance but did not alter the colour. The diamond was next put on a sensitive photographic film and kept there for twenty-four hours. On developing, a strong impression was seen.

β - and γ -Rays produce Phosphorescence.

10. This experiment shows that the alteration of the colour is not due to the phosphorescent state of excitement to which the diamond had been constantly subjected during eight weeks. The colouring action is cut off by a thin screen of quartz, whereas the phosphorescing action is kept up by rays which pass through quartz. It is therefore evident that the coloration is due to the α -rays, or atoms of helium, shot from the radium compound (26, 29, 33). The phosphorescence is produced by the β - or γ -rays (19, 26, 43), which readily pass through glass and quartz.

Persistence of Acquired Radio-activity.

11. The acquired radio-activity of diamonds persists for a longer time than I have been enabled to measure, and resists the most violent treatment I have applied to them.

A large brilliant cut diamond of pure water assumed a fine green colour after having been kept for sixteen months (from May, 1904, to Sept., 1905) in a bottle and covered with powdered radium bromide. At the end of that time it was highly radio-active. This diamond has been carried about in my pocket, off and on, since 1905, and has been tested on a sensitive photographic film at intervals of a year or more. No appreciable difference in its radio-activity can be detected from that which it possessed when first removed from the radium bromide in Sept., 1905. Examined at the present time, nine years after its removal from the bottle of radium bromide, it is luminous in the dark, it rapidly discharges a sensitive electroscope when held near it, and produces scintillations on a zinc sulphide screen as if it were a radium compound.

12. A diamond of good water was selected from a stock of inactive stones, and put in a tube of radium bromide for seventy-eight days. At the end of that time it had assumed a greenish colour, and was highly radio-active. It was then heated to 50° C. in a mixture of fuming nitric acid and powdered potassium chlorate for ten days, the acid mixture being daily renewed (3, 9, 32). The only effect of this acid treatment was to remove a slight dull darkening on the surface, and to render the green tint more brilliant.

After well washing and drying it was put on a sensitive film for five hours. On developing it was seen that the stone had made a good impression on the film.

13. The stone was then sent to a diamond cutter to be cut into a brilliant. On receiving it back it was quite white and free from trace of colour. The stone was then placed on a sensitive film and kept in darkness for twenty-two hours. On developing no impression was apparent, although, before cutting, the active diamond had impressed a film in five hours (12, 16).

Effect of Heat on Induced Radio-activity.

14. A New South Wales diamond which had always been kept away from radium salts, was tested in the electroscope (2) and found to give a fall in two seconds, the natural leak being 180 seconds. The stone was then put in a silica crucible and heated in an electric tray furnace until visibly red. No change was observed. After five minutes—at, say, 700°C .—it was allowed to cool. The time of discharge in the electroscope was found to be six seconds.

15. The diamond was then packed in a silica crucible with graphite and heated with a Meker burner to 700°C . several times, cooling and testing the diamond each time when cold.

Heated to 700°C . for 10 mins. and cooled, time of fall =	6 secs.
„ 15 „ „	= 10 „
„ 20 „ „	= 10 „
„ 20 „ „	= 30 „

It was now left for the night, and measurements resumed next day.

Heated to 700°C . for . . . 60 mins., time of fall =	9 secs.
„ in new graphite for . 30 „ „	= 7 „

New graphite again used.

Tested again after 48 hours, time of fall	= 4 secs.
Heated to 700°C . for 30 mins., and allowed to cool	
for 2 hours, time of fall	= 2 „

The diamond after the last measurement (2 secs.) was laid on a sensitive film and kept in the dark for twenty-one days; on development it gave a good image.

This experiment shows a temporary loss of activity by the heat treatment followed in a short time by complete recovery.

16. A Kimberley diamond, rather flat, octahedral shaped, was kept in a bottle of dry radium bromide for some weeks until it was quite green. By means of a steel wheel fed with diamond dust part of one face was cut away, and the surface of an adjoining

face was just removed, the adjoining corner thus being freshly exposed diamond crystal. It was put on a sensitive film in such a position that it could be subsequently examined and compared with the developed image, so that the active portions of the surfaces, natural and ground off, could be seen. It was allowed to act for five days, when the film was developed. The result indicated very decidedly that where the surface of the diamond had been removed it was no longer radio-active (13).

Experiments with a very Active Diamond Crystal.

17. A fine crystal of diamond from Kimberley which had been kept in a bottle of radium bromide for some months was tested on a sensitive film and in the electroscope. It was found to be highly active, and was set aside for further experiments. It was luminous in the dark, quickly discharged the electroscope, and caused an inactive diamond held near it to phosphoresce. It was put on the surface of a screen coated with small crystals of barium platinocyanide, and caused scintillations the same as on a blende screen, but feebler (11, 26, 27, 30, 33).

18. A blende screen was made by coating a glass slip with very sensitive zinc sulphide. This was laid on the diamond, the ZnS side next the diamond; the scintillations were easily seen through it in all their characteristic appearance, with concentration at the edges and corners. A piece of aluminium sheet, 0.06 mm. thick, was moved about between the screen and crystal of diamond, and there was no doubt whatever that the aluminium stopped all the scintillations. It was absolutely dark where the aluminium covered the crystal.

19. The diamond (17) was then held in contact with the card back of a platino-cyanide of barium screen. The luminous patch due to β - or γ -rays, or to both, was quite evident, moving about as the diamond was moved. The sheet of aluminium foil, used in the former experiment (0.06 mm. thick) was put between the crystal and the back of the screen, and there was little, if any, diminution in the luminosity. It is therefore quite certain that the radio-active diamond gives off other rays beside α -rays, and that the rays can penetrate aluminium 0.06 mm. thick and the card back of the screen.

20. The diamond (17) was put into various fluorescent solutions (uranine in water, Silberrard's *p*-nitroso-dimethylanilinenaphthaline compound, and quinine sulphate). It did not occasion the slightest fluorescence, although its own faint luminosity could be seen in the liquid.

21. The active diamond (17) was cemented to a plate of glass, and six small pillars of lead cemented round it the same height as the stone. The whole was inverted on a sensitive film, and kept in the dark for 2.25 hours. Another experiment was then tried with the same apparatus, only altering the position of the crystal so that the lead pillars were opposite the angles of the crystal. The exposure in this case was 6.5 hours. The pictures on development showed a strong

radiation extending some distance round the diamond (six or eight diameters), and the lead pillars showed strong shadows (Plate 9, fig. 1).

22. The same experiment was repeated three times with the interposition of one, two, and three thicknesses of aluminium foil 0.01 mm. thick, each was exposed the same time (two hours), and all were developed together. Each showed strong action near the diamond. One thickness allowed the shadow of the lead pillars to be easily seen. Two thicknesses showed the shadow with difficulty, and three thicknesses only showed the shape of the diamond itself.

23. The crystal (17) was removed from its circle of lead pillars (21). A small cell of brass tube 0.5 inch in diameter had six slots cut in it with a file. The diamond was mounted in such a position that the three corners of the triangular surface that touched the film should come opposite three of the slots. These experiments show that the diamond is giving off β -rays copiously (fig. 2).

γ -Rays from the Radio-active Diamond.

24. The diamond (17) crystal was fixed with its sharpest point upwards in a small thick cell of brass. Exactly over the point was a small hole 0.5 mm. in diameter and 5 mm. long. On the top was a piece of sensitive film enclosed in black paper. The whole was kept in the dark for three hours, when a fair image of the hole was obtained on development. The apparatus, with another sheet of sensitive film in it, was fixed between the pointed poles of a powerful electro-magnet, and a current of 30 amperes was passed through for three hours. The current was then shut off, and the film shifted sideways for half an inch, and the action of the diamond without the magnetism was allowed to go on for another three hours. It was then developed, and both spots appeared about the same intensity.

25. The diamond crystal (17) in its brass box had a thin plate of clear mica put over the hole, and a sheet of lead over that. All was wrapped in sheet lead, and so kept for about six months. There was an extremely faint but hardly appreciable darkening of the mica at the position of the hole.

26. After the above experiment the diamond was kept in its brass box for two years, and then laid on a sensitive film and kept there for three hours. On developing, a spot of action was seen, showing that the diamond was still radio-active. It was removed from its brass cell and examined in the dark on a blende screen. It gave plenty of scintillations easily visible without a lens. Experiments showed that it still gave out, along with α -rays, also β - and γ -rays (10, 19, 42, 43).

27. A small light-tight box was fitted as a camera. The arrangements were such that the image on the sensitive film was 1.5 times the size of the object. A photograph of the radio-active diamond (17) was taken by the light of its own scintillations

on the blende screen (17, 26, 30, 33), giving forty-eight hours' exposure (fig. 3*a*). The three bunches of luminosity come from the corners of the crystal that are in contact with the screen. The photographic impression is certainly discontinuous, appearing granular, corresponding to the granular character of the screen. It appears that the different grains shine and continue to shine by their own residual phosphorescent light under the impact of the α -particles. In a further experiment the diamond was illuminated by the arc lamp, and a photograph was made of the diamond crystal *in situ* as well as of the screen. This gave a good image of the stone, and also of the granular surface of the screen (fig. 3*b*).

28. It is certain that, in addition to α -rays, the diamond (17) gives off a considerable amount of other rays (10, 19, 26, 42, 43). This is shown by the early experiments, where photographic images with the diamond were obtained through one, two, three, and four sheets of aluminium foil—each 0.01 mm. thick.

29. The crystal of active diamond (17), with which most of these experiments have been made, was examined crystallographically by Dr. TUTTON, who reported to me that the crystal is an apparent octahedron—but composed of two supplementary tetrahedra showing on three of the edges the usual grooves where the interpenetration of the tetrahedra is not complete.

Each of the eight sides of the diamond was photographed by its own radio-activity (fig. 4).

30. Experiments show that exposure of a zinc-sulphide screen to the impact of electrons from the negative pole in a vacuum tube does not cause scintillations. It appears that only α -rays (positive atoms) produce this effect (11, 17, 26, 27, 33); it was therefore interesting to see if scintillations could be produced by bombarding a sulphide screen with a stream of positive atoms produced in a "Thompson" tube. An apparatus was fitted up having a zinc-sulphide screen to receive the positive discharge—but no effect of scintillation could be observed.

Action of Radium Emanation on Diamond and on other Bodies.

31. After repeated observations on the action of radium on various substances, it was seen that diamond behaved differently to glass, quartz, and other materials, especially if the action of the radium had been continued for some length of time. The following experiments were made to see if definite light could be thrown upon this point. Some plates and crystals of pure quartz, lead glass, FARADAY'S borosilicate lead glass, and three diamonds were selected—well cleaned, and exposed upon a sensitive film for twenty-four hours. On development it was seen that all were inactive, except in the case of two of the diamonds, but from these the action was so slight as to be only just visible upon the film. These objects were now laid upon a table of clean platinum gauze and enclosed in an air-tight glass vessel, together with an open bottle containing pure radium bromide. They were allowed to remain

exposed to radium emanation (33) for forty-eight hours; they were then removed from the chamber and laid upon a sensitive film for twenty-four hours. Upon development each object was found to be active and there was nothing to show that the three diamonds had acted differently to the quartz or glass (fig. 5). The objects were now all boiled in dilute nitric acid and thoroughly washed in clean water. They were placed on a film and allowed again to remain for twenty-four hours; on development it was seen that practically the whole of the "activity" had been removed—the two diamonds that originally were very slightly active had, perhaps, gained a little, but all the other objects had lost their temporary activity.

32. The experiments were still further extended. Two fragments of lead glass and one diamond crystal that had been buried in radium for over two years and had become deeply coloured, the diamond green and the lead glass brown, were removed from the radium and cleaned as far as possible with a dry brush. They were kept upon a film for five days. On development the photograph showed three equally dense black patches. The glass and diamond were now boiled in dilute nitric acid, thoroughly washed, laid upon a film, and kept there for eighteen hours. Upon development the pieces of glass were seen to have almost lost their activity—the diamond gave a dense black impression. The objects were now placed in a mixture of fuming nitric acid and potassium chlorate and kept just short of boiling point for six hours, frequently removing the weakened solution and adding fresh acid and chlorate (3, 9, 12); they were then thoroughly cleaned, dried, and laid upon a film for eighteen hours. On development the glass blocks gave impressions slightly fainter than before, while the diamond still gave a dense black image almost as strong as before the treatment.

33. An examination with a zinc-sulphide screen showed that the diamond caused brilliant scintillations from its edges and corners and a few erratic scintillations could be detected round each of the fragments of glass (11, 17, 26, 27, 30). The net result of these experiments is to show that although the well-known condensation of emanation (31) upon crystals and objects gives rise to photographic markings of patterns as described in this research and in previous papers by Sir ERNEST RUTHERFORD* and other observers, this superficial activity can be easily and completely removed by washing in dilute acids. The two kinds of acquired activity are illustrated in figs. 6 and 7. Fig. 6 is a radiograph of a crystal of quartz that had been rendered active by exposure to radium emanation, while fig. 7 is a radiograph of a crystal of diamond that had been covered in a bottle with radium bromide crystals for many months. While the former points to a superficial coating of active matter, the latter is more suggestive of a brush discharge from the corner of the diamond crystal. If the action of the emanation is allowed to continue until colour changes are produced both in glass and diamond, the activity is retained even after many

* "Distribution of the Intensity of the Radiation from Radio-active Sources," by Sir ERNEST RUTHERFORD, F.R.S., 'Phil. Mag.,' August, 1906.

hours boiling in powerful acids, and the diamond retains its activity with much greater tenacity than the other materials—nothing short of actually cutting away the surface will remove it. The diamond crystal—that had been rendered active by immersion in dry radium bromide for some months in 1906 (17) and has been treated with acids, heated, and used in hundreds of experiments since—is apparently as active now as when it was removed from the radium, and still pours out streams of α -rays* (Plate 10). Fig. 8 shows two radiographs of this crystal, having an interval of five years between them. Fig. 8*a* was taken in 1909 and fig. 8*b* a few days ago.

34. As in the case of diamond, a quartz glass dish after the action of radium retains its colour and activity, and continues to give off α -, β -, and γ -rays (fig. 9). One-half had a film of aluminium, 0.035 mm. thick, interposed between the dish and the sensitive plate. Vessels of pure fused silica that have been much used for the crystallisation of radium salts become coloured a purplish tint, similar to that assumed by soda glass in similar circumstances. On heating such a coloured vessel with a spirit lamp to a temperature much below a red heat it suddenly phosphoresces a bluish colour and at a red heat becomes colourless.

35. A small equilateral prism was cut from a block of heavy glass (sp. gr. 3.87), polished on its three refracting faces, but left rough ground on the triangular top and bottom. It was put into a bottle and covered with dry crystals of radium bromide for fifteen hours. At the end of this time it was removed, well washed and placed on a sensitive film, base downwards, for twenty-two hours. On development a strong action was apparent with overflow radiation along the sides and the continuation of the faces in triangular lines (fig. 10) as observed by Sir E. RUTHERFORD.

36. One of the rough ground bases of the prism was now polished over the greater part of its surface, leaving a strip of glass along one edge in its original unpolished condition. This end was then laid on a sensitive film for thirty-six hours. On the polished portion of the surface there was absolutely no perceptible action on developing, while the part left unpolished was highly active—as in the first experiment with the prism (fig. 11).

37. The prism was now laid on a sensitive film on one of its polished faces for twenty-four hours. On development slight action was observed where the polished face touched the sensitive surface and a much stronger overflow action with continuation of the edges of the prism face in straight lines as mentioned above (fig. 12).

38. The same prism was taken, and a diagonal scratch made with a writing diamond across the same face that touched the film in the last experiment. It was laid with this face downwards on a sensitive film for twenty-four hours. On

* These experiments are closely connected with those of SWINTON, COLLEY, RAMSAY, and others, who have shown that helium is driven into the glass walls of a vacuum tube even by the slower moving cathode rays. The high speed α -particles evidently are driven into the diamond, below the molecular surface.

development the image showed action as before where the face touched the film, but the line of scratch where the surface of the glass had been abraded by the diamond was blank, showing no action whatever (fig. 13).

39. A triangular plate, about 1 mm. thick, was polished on its three edges, and kept in a bottle of solid radium bromide for sixty-eight hours, then laid on a sensitive film for four hours. There was very little action to be seen on development on the part where the face touched the film, but there was strong action radiating from the edges, with a continuation of the line of edge from each point (fig. 14). The plate was now cut into two equal parts, and the two halves, separated about a centimetre, were laid on a sensitive film and there kept for forty-eight hours. On developing, it was seen that the action of the flat surface was the same as before, but while the overflow action from the original corners was also the same, there was no action at all along the cut surface (fig. 15).

40. A glass tube that had contained 25 mgrm. of pure radium bromide was cut in half to remove the radium, and well washed and boiled in acids. It was of a dark blue colour. After being in a cabinet for many months the two halves were laid on a sensitive film in a line, the cut surfaces opposite each other and separated about 2 mm. After four hours' contact the film was developed when the appearance presented that of a streaming brush discharge from the two ends of each half—the part where the tubes themselves rested having made no impression (fig. 16).

Superficial Action of Radium on Mica.

41. Radium bromide has been imported from the Continent in small ebonite boxes covered with a disc of mica. One of these discs was first well washed to remove any adhering grains of radium salt—it was then split into four flakes. The upper flake, of a strong brown colour, discharged the electroscope in three seconds. The next film, also showing brown discolouration, required 3.5 seconds. The third film, not discoloured at all, required twelve seconds, while the last film, which had been furthest from the radium, required eighteen seconds for discharge, showing that the greater part of the activity was near the surface and corresponded with the coloration.

Action of X-Rays on Diamond.

42. Experiments were instituted to ascertain how X-rays affected the diamond. A tray full of crystals of diamond was exposed to X-rays from a hard tube, covered in card and velvet so as to prevent interference from the luminosity of the glass. Most of the stones became luminous—but in different degrees. Two stones specially were noticed. One large stone shone very brightly, with a blue

tint, the other, smaller, was only just luminous. A sheet of aluminium, 3.2 mm. thick, was now interposed in the path of the X-rays, when the phosphorescence of the large bright stone was considerably reduced, while that of the small faint stone was not diminished at all.

Action of β -Rays on Diamond.

These two diamonds were subjected to the action of solid radium bromide, and the intensity of the phosphorescence thereby induced was seen to be of the same character as that caused by the X-rays. An extension of the experiment with radium, described in the next paragraph, showed that the effect of phosphorescence was mostly due to the β -rays (10, 19, 26).

43. An apparatus (fig. 17) was fitted so that the active rays from a bottle of radium bromide (A) should pass through a tube drilled through a lead block (B), and allowed to pass upwards on a diamond (c) supported on a plate of aluminium, 0.02 mm. thick. This was arranged between the poles of a powerful electro-magnet, so that the active rays from the radium should pass through the hole and act on the diamond when the magnetism was off, and be deflected from it when the magnetism was on.

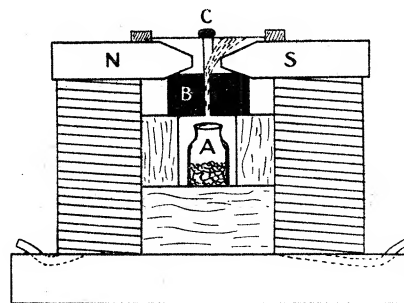


Fig. 17.

A screen of barium platinocyanide put over the hole in the lead block showed a circular spot of phosphorescence. This luminosity vanished when magnetism was turned on, and reappeared when it was turned off, showing that the luminosity on the screen was chiefly due to the β -rays (10, 19, 26). The two large and small diamonds used in the last experiment were put side by side on the aluminium, and the support so arranged that it could be moved sideways to put either stone over or away from the hole in the lead block. It was easy to see by small movements of the support that, as in the case of the X-rays, the large stone was much more phosphorescent than the smaller stone. There was considerable residual luminosity, each of the stones continuing to glow with its relative intensity when effectually removed from the radium. Having found the position of maximum brightness for the large stone when over the radium, the current was turned on, so as to deflect the β -rays. At once the glow declined, and the residual phosphorescence faded. On taking the current off, so as to allow the β -rays again to come into action, the brilliancy increased again. There was no doubt as to the action, although the undeflected γ -rays and the residual luminosity tended to obscure the observations.

44. The results described in this paper may be summarised as follows:—Various objects, diamond, ruby, garnet, quartz, gold, platinum, &c., also the phosphorescent substances yttria, calcium sulphide, zinc blende, and barium platinocyanide, are bombarded in a high vacuum by cathode rays, and in no case can any permanent activity be recognised either by photographic or electrical means (1, 2, 3, 4, 5, 6, 7).

Exposure to radium emanation confers temporary radio-activity on all bodies that have been tried; apparently due to the condensation of the emanation on the surface. This transient activity can be completely removed by washing in dilute acids (31).

Many substances become coloured by direct exposure to radium, the colour depending on the substance. Diamonds take a full sage-green tint, the depth depending on the time of exposure to the radium (33).

In addition to change of colour diamond also becomes persistently radio-active continuously giving off α -, β -, and γ -rays. The acquired colour and activity withstand the action of powerful chemical agents, and continue for years with apparently undiminished activity (12, 31, 32).

Removing the surface by mechanical means removes both colour and radio-activity (13, 16, 35, 37, 41).

The appearance of an auto-radiograph made by placing an active diamond crystal on a sensitive photographic plate, and the visual examination of its "scintillation" luminosity, suggest that there is a special discharge of energy from the corners and points of the crystal (18, 21, 23, 27, 33).

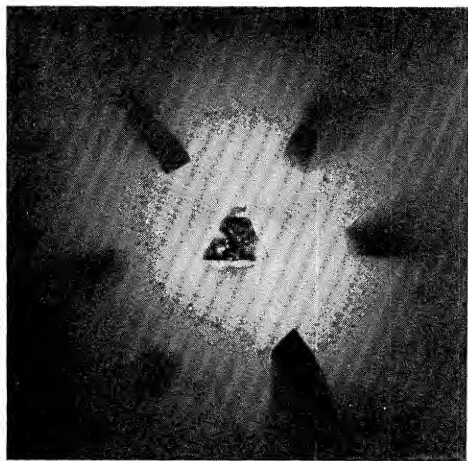


Fig. 1.

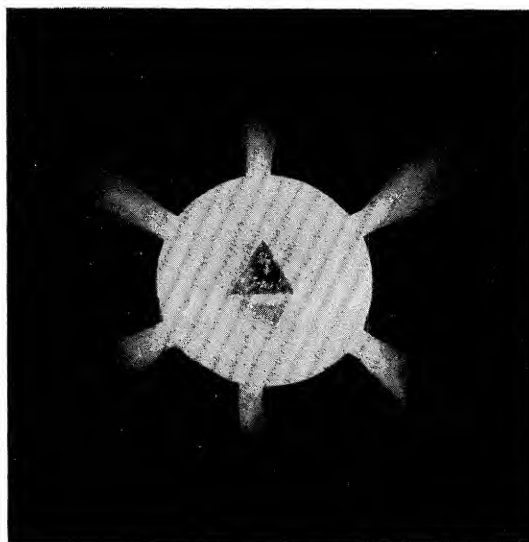
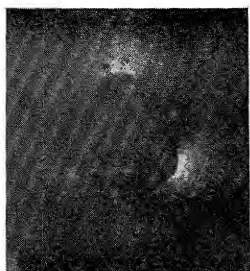
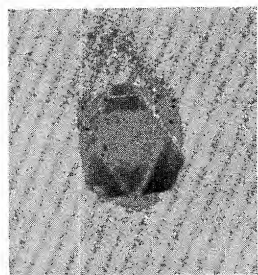


Fig. 2.



a



b

Fig. 3.

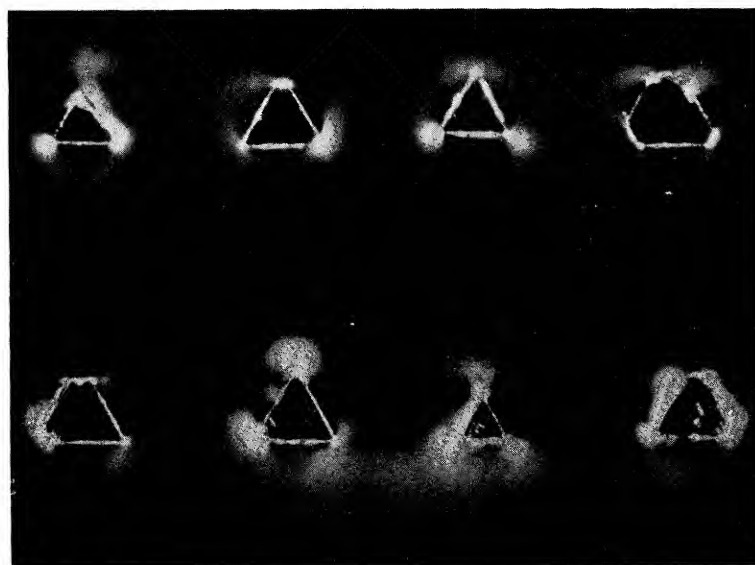


Fig. 4.

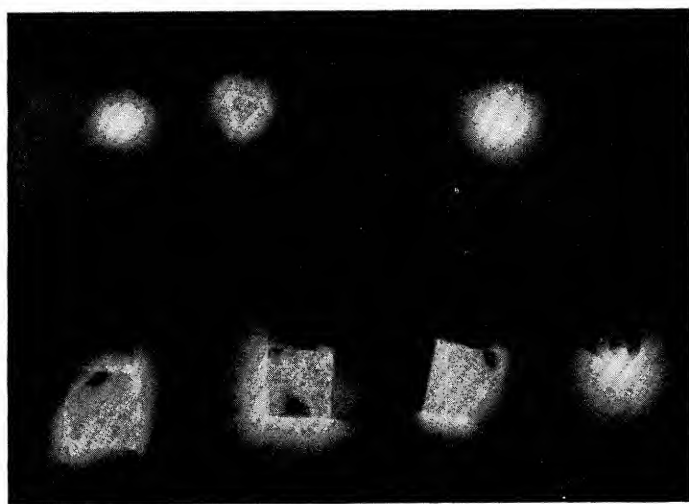


Fig. 5.

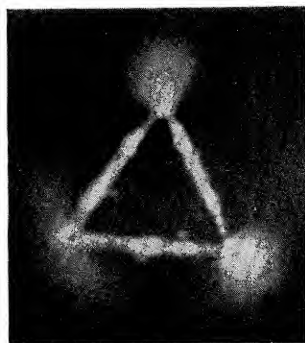
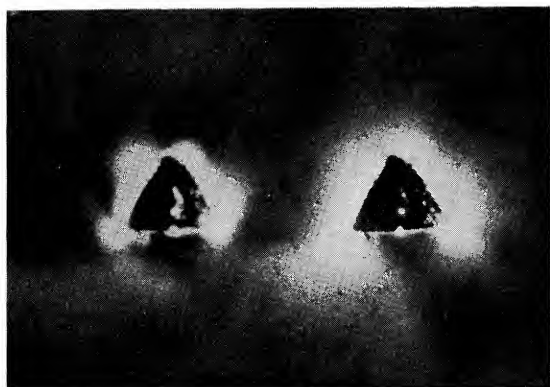


Fig. 7.



Fig. 6.



a *b*

Fig. 8.

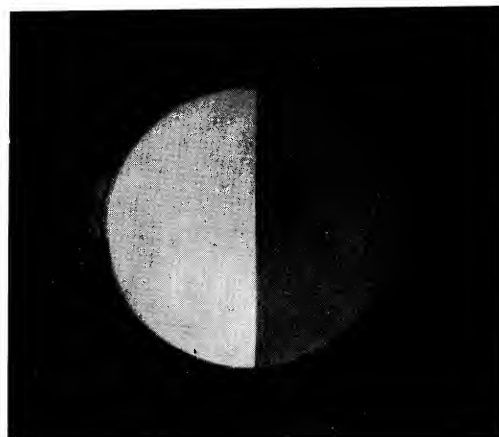


Fig. 9.

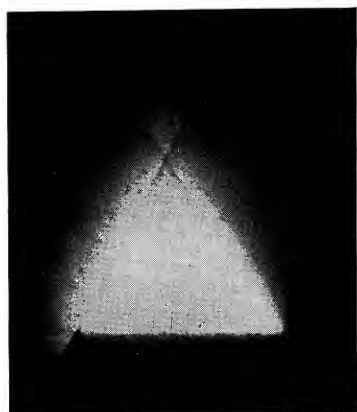


Fig. 10.

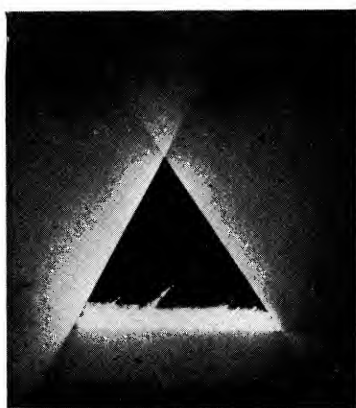


Fig. 11.

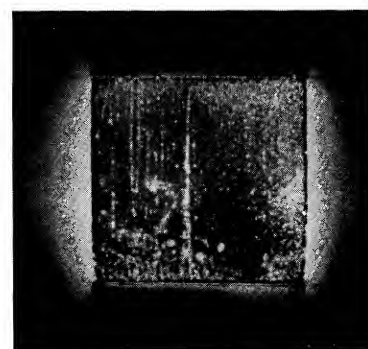


Fig. 12.

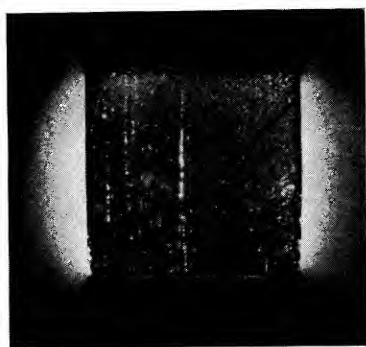


Fig. 13.



Fig. 14.

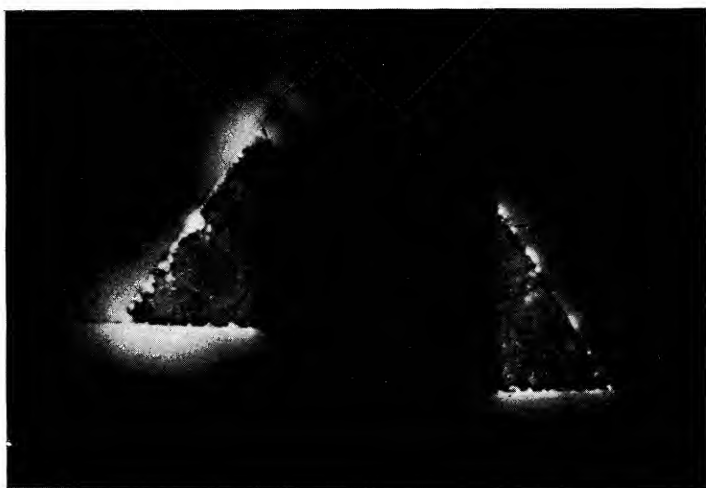


Fig. 15.



Fig. 16.



Fig. 1.



Fig. 2.



a



b

Fig. 3.



Fig. 4.



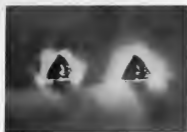
Fig. 5.



Fig. 7.



Fig. 6.



a b

Fig. 8.



Fig. 9.



Fig. 10.



Fig. 11.

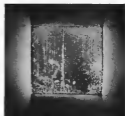


Fig. 12.

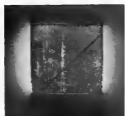


Fig. 13.



Fig. 14.

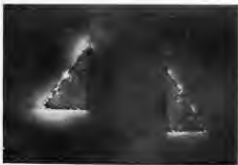


Fig. 15.



Fig. 16.